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A vision system for the online quality monitoring of industrial manufacturing

Giuseppe Di Leo*, Consolatina Liguori, Antonio Pietrosanto, Paolo Sommella

Department of Industrial Engineering (DIIn) – University of Salerno, Via Giovanni Paolo II, 132, 84084 Fisciano, SA, Italy

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ABSTRACT

The design of an image based measurement system for the online inspection of electromechanical parts is described. A two-camera architecture is introduced in order to highlight all the required details involved in the measurements. The design takes into account both the interfacing and the real-time issues that assure an effective online operation. The description of the measurement system and the corresponding installation on the production line points out a methodological approach to the design of these kinds of measurement systems. The paper provides details about the algorithms for the localization and the measurement of the required quantities, as well as the calibration procedure and the error correction. Experimental tests for the performance evaluation are presented and discussed in terms of timing and accuracy.

1. Introduction

Industrial production is strongly interested in the advantages offered by image-based measurement systems for product inspection: contact-less inspection of products means reduction of invasiveness, reduction of costs, more favorable sampling of parts, statistical significance of the results and better awareness of the operators about the line operation conditions [1–5]. Traditional areas, where artificial vision systems have been successful, include the contactless inspection of manufactured goods such as automobiles, semiconductor chips, food and pharmaceuticals. The goal is to reduce the production costs due to human intervention in the defect analysis or due to the discard of defective parts by ensuring consistent product quality [6]. Image-based systems can also automate the manufacturing processes by controlling equipment such as industrial robotic arms. In many cases, the process parameters can be tuned through a feedback network, which modifies the parameters of the industrial process as soon as a trend is detected which would give raise to defects if it were not promptly compensated.

Machine vision systems have also taken an important role for the measurement of the mechanical (stamped metal) components to ensure that the corresponding parts fall within given specification limits. The key to their success can be found in distinctive attributes such as flexibility, reliability, higher operating speeds, consistency and accuracy, which have made them competitive if compared to traditional measurement systems.

The development of the artificial vision system is strongly influenced by design models based on the reuse of widely-adopted software library components and on general-purpose vision hardware. Consequently, the chosen application architecture and the algorithms adopted in the single processing stages are often depending on previous experience and trial iterations that eventually lead to the final tuning of the automatic system.

In order to optimize the development cycle, this paper intends to introduce a more schematic and progressive approach to the design of vision-based measurement system in the industrial context: the adoption of simple rule-based sequence of decision is proposed aiming to improve both the phases of the calibration and the evaluation of measurement uncertainty.

Following the approaches suggested by the scientific literature [7–10] about the image based measurement systems for industrial application, camera calibration as well as the analytical calculation and correction of systematic effects may be carried on according to a well known framework.

Under this point of view, the specific proposed measurement system will act as a case study for the demonstration of the approach. The measurements performed by the proposed automatic system in order to check the matching of the electro-mechanical parts to the manufacturing requirements can be grouped into different classes: i) widths and heights of given parts, ii) distances between lines to be located and reference lines; iii) angles

* Corresponding author.
E-mail addresses: gdileo@unisa.it (G. Di Leo), tliguori@unisa.it (C. Liguori), apietrosanto@unisa.it (A. Pietrosanto), psommella@unisa.it (P. Sommella).

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between lines to be located and reference lines; iv) presence of unwanted defects.

In the following, after a description of the overall structure of the measurement station, the procedures for the calibration, for the measurements and for the error correction are presented in terms of an extensive experimental verification. For each one of these aspects, the criteria which eventually led to the design choices will be detailed.

2. System description

The proposed measurement system allows the detection of defects and the dimensional monitoring of electromechanical parts, which include conducting wires and plates put onto plastic or metal supports and leverages, with different employments in appliances and devices, such as interrupters or locks. The traditional control of all the pieces produced is carried out by an operator. The pieces at the end of the production line are arranged into a matrix support containing 25×20 pieces; the typical defects are detected by the operator inspection through a magnifying lens. Periodically a single piece is checked by the laboratory quality.

The introduction of the proposed system has allowed to check online all the produced items. The measurements of each piece are compared to reference values and, whenever they are outside the given tolerances, the piece is discarded. The measurement system is positioned at the end of the production line at Bitron plant in Alatri, Italy. It is composed by two cameras connected via Ethernet bus to a control industrial PC. The system components are shown in Fig. 1. Two cameras, hereinafter labeled *top* and *front*, are needed because the lengths to be measured can be observed on two different sides of the product. There is also a National Instruments data acquisition board NI PCI-6601 connected to the processing unit through the USB bus; its digital I/O lines are used for the information exchange with the PLC (Programmable Logic Controller) that manages the production line. For each piece the following sequence of tasks is operated by the system:

– waiting for a new piece;
– image acquisition from the top camera;
– turning on the backlight illuminator;
– image acquisition from the front camera;
– automatic image processing;
– visualization of the results.

The software was developed in LabVIEW; the main screenshot of the application is shown in Fig. 2a); while the state diagram of the application is depicted in Fig. 2b). In the following, specific aspects related to the metrological issues are detailed.

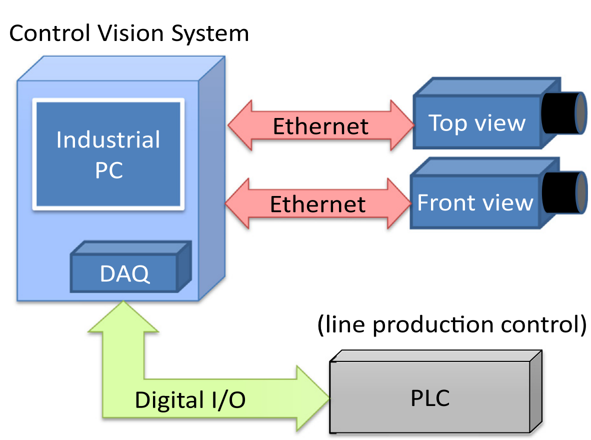

Fig. 1. The measurement system.

Two images are acquired by two Imaging Source DFK 23G445Gigabit Ethernet cameras, equipped with a Sony ICX445AQA progressive scan CCD sensor.

The interline CCD solid-state image sensor has a diagonal of 6.0 mm (Type 1/3″) with a square pixel array and 1.25 M effective pixels. Progressive scan enables all pixel signals to be output within 1/22.5 seconds. The image size is 1280×960 pixels. Both cameras use a Fujinon lens CF25HA-1 with a focal length of 25 mm, an F/number of 1:1.4, an iris range of [1.4, 22] and a minimum object distance of 0.1 m.

The lighting system consists of an LED backlight illuminator, which can be programmatically switched on and off, and an additional single white LED.

The layout of the components of the vision system is shown in Fig. 3. As previously introduced, for each piece under measurement two images are acquired respectively by the top view and front view camera. The white LED is constantly lit to weakly illuminate the piece from a direction opposite to that of the front camera, while a backlight illuminator is activated only during the image acquisition by the front camera.

3. The vision procedures

The images acquired by top and front cameras undergo two completely separated processing procedures. They will be described in the following.

3.1. Top image processing

The aim of this task is the measurement of the lengths L_1, L_2, L_3, L_4, and L_2', L_3', L_4', which are deemed critical in the design specifications. Furthermore, the width L_5, L_5' and height L_6, L_6', of the tin-plated area of the metal blades are measured. All dimensional measurements are shown in Fig. 4. The algorithm was developed using typical image processing functions. In particular, functions of the library NI Vision by National Instruments have been adopted. All the measurement functions are applied to associated rectangular regions of interest (ROIs) defined by the user relative to a main reference coordinate system anchored onto the left top corner of the object (shown as two arrows in red in Fig. 4).

The main steps of the algorithm for top image processing are the following

- extraction of luminance and saturation planes from RGB input image;
- application of morphological and thresholding operators to the luminance image to compensate minor variations in brightness;
- search for the location and orientation of the main reference coordinate system (whose purpose is i) to detect possible minor changes of the object position in the image with respect to the expected position and ii) to compensate them by accordingly roto-translating the ROIs;
- search for straight lines approximating edges to be used as reference lines (dotted green lines in Fig. 4), $r_1, \ldots, r_7, r_1', \ldots, r_7'$, for the length measurements. The search for these lines is performed with a two step procedure: i) localization of the edge points along a set of search lines (horizontal o vertical) within the search region; ii) calculation of the orthogonal best fit line for the detected edge points.
- measure L_1, L_2, L_3, L_4 and L_2', L_3', L_4' (shown in the Fig. 4) as the distance between a proper pair of reference lines.
- measure L_5 and L_6 as the width and the height, respectively, concerning with the part of the tin-plated metal blade element. They are detected using a function that thresholds the image to